Aquatic Metabolism and Water Quality in the Fifth Avenue Dam Pool of the Lower Olentangy River in Columbus, Ohio

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Abstract

Dissolved oxygen diurnal patterns of aquatic systems can be useful for indicating the presence of organic pollution. Changes in diurnals can be seen after pollutant loadings increase in a water body, especially after heavy rain events that cause runoff and combined sewer overflow. A YSI 6600 sonde was installed on December 3, 2008 in the Fifth Avenue Dam pool of the Lower Olentangy River, which experiences urban and agricultural runoff, as well as combined sewer overflow events. Thirty-minute interval dissolved oxygen (DO) readings were analyzed for the period June 1, 2011 to January 31, 2012. Diurnal curves were analyzed for twelve 24-hour periods from June to September, 2011 during base flow conditions, as well as July 24 and August 19, 2011 during flooding conditions to capture the effect of flow on DO diurnal patterns. Under base flow, diurnals exhibited typical patterns of maximum and minimum DO levels at dusk and dawn, respectively. During floods, DO levels crashed, then recovered within 48 hours once flows were restored to normal levels. The number of DO excursions below certain concentrations was examined from June 2011 to January 2012. DO levels below 5 mg/L were found to exist most frequently during July and August. DO levels did not drop below 3mg/L during the study period; therefore, the dam pool never reached hypoxic conditions. Diurnal curves were also used to analyze gross primary productivity (GPP) and respiration (R) of the impoundment using the dawn-dusk-dawn method. Both flow and solar radiation influenced GPP levels and diurnal patterns.

Introduction

Dissolved oxygen is often used as an indicator of water quality. However, the frequency at which samples are taken can cause significant differences in the values obtained. Continuous monitoring of dissolved oxygen provides a better “picture” of biological activity and water quality than one-time measurements. Photosynthesis and respiration cause daily fluctuations in dissolved oxygen. These diurnal patterns show an increase in DO during the daytime as photosynthesis occurs, and a decrease in DO at night while respiration takes place. Typically, maximum DO levels occur at dusk, and minimum levels occur at dawn. These daily fluctuations can only be captured when DO is measured frequently. In this study, DO levels recorded every thirty minutes and were used to estimate primary productivity. When organic pollutants enter the water column, whether by runoff, combined sewer overflow, or other means, aerobic decomposition diminishes DO levels. Ansa-Asare (1999) concluded that organic pollutant loads significantly affect DO diurnals. Therefore, diurnal dissolved oxygen curves can be used as indicators of pollution and water quality.

Another cause of water quality impairment is flow alteration. The Fifth Avenue Dam, located just south of Ohio State University campus, is a source of flow alteration that has been suggested to be impacting the Lower Olentangy River. The Olentangy River is approximately 150,000 meters long and runs through six counties in Central Ohio (OEPA 2007). It passes through Ohio State University’s main campus, thus providing easy access for students to conduct studies on the ecological function of river ecosystems. The Ohio Environmental Protection Agency has studied the Olentangy River as well, and in their 2007 TMDL report, they found that water quality problems exist at more than fifty percent of the 74 study locations (OEPA 2007).

While many studies have examined the effects of large dams on river integrity, few have documented the impacts of low head dams (<5 m height), and a smaller number have actually investigated the effects of dam removal on water chemistry (Velinsky et al. 2006). Therefore, the goal of this study is to set up a preliminary basis for studying the effects of removing the Fifth Avenue Dam, specifically as it relates to dissolved oxygen and productivity. Objectives include:

1. diurnal curve analysis under various flow conditions
2. calculation of aquatic metabolism (gross primary productivity and respiration) in the Fifth Avenue Dam pool
3. determination of dissolved oxygen excursions below certain concentrations, and
4. comparison of water quality to an upstream reference site.

Based on the data collected, predictions were made about the effect of removing the Fifth Avenue Dam on the water quality and productivity of the Olentangy River within the area of study.

In preparation for the dam removal, several studies have been done specifically on the Olentangy River by Ohio State students and the Army Corps of Engineers. Sediment evaluation is being done by the Army Corps to assess whether dredging will be necessary in the event that toxins are present (Army Corps 2006). Student research has been done predicting the stage, bathymetry, and succession of riparian vegetation after removal (Naegele et al. 2010). Using various approaches to calculating river stage, it can be expected that riparian zone will increase post-removal. Previous studies collecting water samples upstream and downstream of the dam showed seasonal differences in water quality, most likely due to flow and respiration (Chambers 2008). Another study evaluated the biological integrity of the Fifth Avenue Dam pool. Compared to three upstream and one downstream reference site, the dam pool showed the poorest results for physical and biological indices (Walters 2008).

This study will be an important addition to previous investigations, and will provide an updated look at the current function of the Olentangy River prior to the removal of the Fifth Avenue Dam. In the future, this data will be available to watershed managers who are wishing to assess the ecological impacts of dam removal.

Methods

The Olentangy River watershed drains approximately 1,400 square kilometers, the lower portion in Franklin County being 78% impervious cover. Stream flow varies highly among seasons, closely following patterns of precipitation (FLOW 2003). At 2.4 meters tall, the Fifth Avenue Dam is the largest of 12 low-head dams on the Olentangy River, creating a 3,200 meter-long reservoir of impounded water. Water quality in the reservoir is considered to be in non-attainment of biological and ambient water qualities set by the Ohio EPA (Army Corps 2006, OEPA 2007). One site located in the Fifth Avenue Dam pool has been selected for study: the Ohio State University foot bridge (Figure 1).

A YSI 6600 water quality sonde was installed on December 3, 2008 at the foot bridge in the middle of the reservoir. The sonde collects data every thirty minutes, and a relay signal sends it to a computer at the Olentangy River Wetland Research Park (ORWRP). The YSI 6600 was calibrated monthly from June 2011 to November 2011. Depending on river conditions, a pontoon boat, the *ORW Natalie*, or a johnboat was used to retrieve the foot bridge sonde for calibration. Data was collected from June 2011 to January 2012. Specific parameters measured by the sonde include pH, specific conductivity, temperature, and dissolved oxygen. Water level is also recorded by the YSI, and reads 0.25 meters higher than the staff gauge installed adjacent to the

YSI (i.e. a reading of “1 m” on the staff gauge is recorded as “1.25 m” by the YSI). Within this study, all water level readings are from the YSI.

An upstream reference site on the Olentangy River was used as the control location at the North Broadway Street Bridge. This location was chosen because it is in full attainment of Ohio EPA aquatic life use standards and therefore represents natural river conditions that can be compared to conditions in the impounded reach of the river (Ohio EPA 2007). Manual samples were analyzed with a YSI 600 sonde at the upstream reference site as well at the foot bridge site during October and November of 2011. A rope and bucket was used to collect surface water samples from three consistent spots across the North Broadway bridge, and two consistent spots on the foot bridge. These readings were averaged for each sampling date. Water quality in the dam pool could then be compared to that of the reference site.

Diurnal curves of dissolved oxygen were analyzed to calculate respiration and gross primary productivity (aquatic metabolism) of the water column in the Fifth Avenue Dam pool. Heavy rainfall events were taken into account during analysis due to their effect on river flow, which typically causes decreases in productivity and dissolved oxygen. The dawn-dusk-dawn method of productivity analysis was used to calculate gross primary productivity (GPP) and respiration (R) for twelve days during base flow conditions (Hall & Moll 1975; Leonard et al. 1999). Under base flow conditions, dissolved oxygen concentration fluctuates with time in a typical diurnal pattern. Dissolved oxygen concentrations increase during the daytime while photosynthesis of aquatic plant biomass occurs, causing a peak in concentration around dusk. During the nighttime, DO concentration decreases while respiration takes place, resulting in a minimum concentration at dawn. The dawn-dusk-dawn method tends to underestimate gross primary productivity, but it was a suitable method for this study since it simplified the large amount of fluctuation in data taken at thirty-minute intervals (Reeder & Binion 2000).

To calculate GPP, a curve of dissolved oxygen concentration versus time for a 36-hour period (midnight of day one to 6am of day 2) is plotted (Figure 2A). The DO concentrations for the minima, which occur approximately at dawn, and maximum, which occurs around dusk, are recorded. The slope from each minimum to the maximum represents the rate of change of dissolved oxygen with time (in g/m^3-hr). Diffusion is assumed to be negligible since river conditions in the impounded reach are not turbulent enough for diffusion to contribute significantly to dissolved oxygen levels. When the rate of change is plotted, the area below the positive rate of change represents net primary productivity, and the area below the negative rate of change represents respiration, shown in eq 1.1 (Leonard et al. 1999).

$$R = \Delta t \times (r_2) \times D \qquad \text{(eq .1.1)}$$

where: R = respiration (g O_2/m^2-day)
Δt = change in time between dusk and dawn (hrs)
r_2 = absolute value of rate of change between dusk and dawn (g O_2/m^3-hr)
D = average river depth (m)

Gross primary productivity is the area under the rate of change curve, where the height is the difference between positive and negative rate of change, and the width is the change in time between dawn and dusk (Figure 2B). The area under the curve is then multiplied by the average water depth to calculate GPP, as shown in equation 1.2 (Table 3).

$$GPP = \Delta t \times (r_1 + r_2) \times D \qquad \text{(eq. 1.2)}$$

where: GPP = gross primary productivity (g O_2/m^2-day)
Δt = change in time between dawn and dusk (hrs)
r_1 = positive rate of change between dusk and dawn (g O_2/m^3-hr)
r_2 = absolute value of rate of change between dusk and dawn (g O_2/m^3-hr)
D = average river depth (m)

Results

Effects of Flow on Dissolved Oxygen

DO and flow measurements for all data (Figure 3A and a heavy rain event (Figure 3B) show the extraordinary variability of flow (m^3/s) and dissolved oxygen (mg/L). An increase in flow can affect DO levels in several ways. A “wash out” of suspended aquatic plants such as plankton may occur, which subsequently decrease dissolved oxygen levels due to a lack of photosynthesis in the water column. Additionally, turbulence caused by high flows can stir up sediment and reduce the amount of available sunlight for photosynthesis. Another result of high flows is combined sewer overflow (CSO), which is common in the area of study due to the large amount of impervious surfaces that increase stormwater runoff, a leading cause of water quality issues in rivers (US EPA 2007). More specifically, 1.8 billion gallons of precipitation fall on the Ohio State campus area adjacent to the study site each year. Currently, 44% of the campus is covered with impervious surfaces such as sidewalks and parking lots, which do not allow rainwater to infiltrate the soil. Approximately 1.1 billion gallons of that precipitation is directed into the current stormwater infrastructure and flows directly into the Olentangy River (One Ohio State Framework 2011). DO levels are consumed by microbial degradation of organic material that enters the river through CSOs.

On July 24, 2011, a peak flow event occurred that was classified as a “heavy rainfall” by the NOAA Storm Events Database. The dissolved oxygen measurements for July 24-28 2011 were plotted versus time in Figure 3B. After the storm’s occurrence around 5pm on July 24, the DO readings decrease from approximately 8pm on the 24 until 1am on the 25. By 6am on July 25, the DO levels begin to increase again. Normal diurnal patterns are recovered by July 26.This event followed the expected pattern of DO crash and recovery after peak flow. However, there are not enough data to suggest that all peak flow events cause the same response in DO level. The variety of factors that affect DO levels, such as CSO's, flow level, and weather conditions, make it difficult to directly relate river flow to a specific DO response.

Hydrology & Water Quality

A summary of monthly averages of water depth, temperature, specific conductivity, and dissolved oxygen concentration is displayed in Table 1, with maximum monthly averages highlighted in gray. The highest average specific conductivity occurred in the winter during January, indicating higher concentrations of total dissolved solids or salinity. It is possible that the large amount of road salt that is applied during winter months in the Columbus area caused an increase in salinity during January. Maximum average dissolved oxygen concentration also occurred in January; the low average temperatures during this month contribute to higher solubility of gas in water, therefore leading to greater DO levels. The relationship between temperature and dissolved oxygen is further explored in the Discussion.

Dissolved Oxygen Excursions

Dissolved oxygen is important in river systems because it supports aquatic life. If DO concentrations drop below 5 mg/L, conditions become stressful for aquatic organisms (Shifflett et al. 2005). Dissolved oxygen readings were taken every thirty minutes, and the number of DO excursions below 5, 4, and 3 mg/L, respectively, was found for each month (Table 2). July experienced the largest number of excursions, with DO levels dropping below 5 mg/L 94 times during the entire month. Of the excursions below 5 mg/L, three were below 4 mg/L in July and four were below 4 mg/L in August. Dissolved oxygen was not found to drop below 3 mg/L during the study period. The lowest DO reading was 3.28 mg/L, which occurred at 10:30 a.m. on August 22, 2011.

Several factors affect DO concentration in aquatic systems, including temperature and flow. Gases are more soluble in colder temperatures; therefore, DO levels are expected to be higher in colder months and lower in warmer months. This is evidenced in Table 2, in which there were no DO excursions during the cooler temperatures of October to January. There are also more frequent DO excursions in the warmer months of June through August.

Patterns of Solar Radiation and Dissolved Oxygen

Solar radiation is directly related to photosynthesis, and therefore influences dissolved oxygen levels in the water column. When solar radiation is zero at night, respiration occurs and DO levels decrease. During the day as solar radiation increases, DO levels can increase. This expected relationship is demonstrated very clearly in Figure 4A, which shows a diurnal dissolved oxygen curve and solar radiation for a 24-hour period during base flow (14.3 m^3/s). However, under flooding conditions (43.9 m^3/s), solar radiation does not seem to influence DO as directly (Figure 4B). This indicates that both flow and solar radiation create a dynamic interplay that affects dissolved oxygen concentrations in a river system.

Productivity and Respiration

Dawn-dusk-dawn DO, along with gross primary productivity and respiration were estimated for twelve dates during base flow conditions that existed from June 16-October 12, 2011, as well as the two precipitation events on July 24 and August 19, 2011 (Table 3). The maximum GPP value for the dates analyzed occurred on September 11-12, 2011. The maximum respiration rate occurred on August 19-20, 2011, which was the date of a flash flood event in Franklin County.

Data highlighted in gray indicate two precipitation events of importance. The first is a heavy rainfall event, which occurred on July 24, 2011 as listed in the NOAA Storm Events

Database, and the second is a flash flood that was listed in Franklin County, Ohio on August 19, 2011 (NOAA 2012). These events were examined for their effect on dissolved oxygen, respiration, and gross primary productivity.

GPP was plotted versus flow (Figure 5). Since GPP is related to dissolved oxygen levels, it can be expected that GPP will respond similarly to peak flow. However, this figure does not reveal a strong trend of decreasing GPP with increasing flow. More data is needed at various flows to determine how GPP changes with flow, and whether there is a maximum flow value above which GPP levels can be expected to drop. In the future, new stormwater management techniques could be implemented to mitigate flashy runoff into the Olentangy River. This will help maintain dissolved oxygen and gross primary productivity in the water column, instead of inducing large swings in DO levels and crashes in GPP. In turn, this will create a healthier environment for aquatic organisms in the river.

Respiration estimations for the twelve base flow dates and two precipitation events are listed in Table 3. Interestingly, after the heavy rain event on July 24, 2011, respiration drops to zero at the time of peak flow (43.9 m^3/s). During the flash flood event on August 19, 2011, respiration was highest out of all the dates that were analyzed. However, it is important to note that the average flow on August 19, 2011 was 2.3 m^3/s, which is much lower than the 43.9 m^3/s flow on July 24. Therefore, it seems that high flow affects respiration more than a single flash flood event that does not persist long enough to increase flows to a level that diminishes respiration.

Comparison to Upstream Reference Site

Table 6 lists temperature, dissolved oxygen, and specific conductivity readings taken on four dates in October and November, 2011 at the upstream reference site (North Broadway

Bridge), and the foot bridge in the Fifth Avenue Dam pool. An unpaired T-test was conducted to compare water quality in the dam pool to that of the upstream reference (Table 4). Differences in temperature, conductivity, and dissolved oxygen between the dam pool and upstream reference were not significant. However, there are not enough data to make clear conclusions about the effect of the Fifth Avenue Dam on water quality in the dam pool.

Discussion

Based on current literature, several predictions can be made about the effect of removing the Fifth Avenue Dam on water quality in the two-mile impoundment that it creates. Dams are traditionally used to provide power, flood control, and a supply of water for drinking, irrigation, and recreation (Bednarek 2001). However, they also have implications of altering physical, biological, and chemical characteristics of a river and its floodplain (Bednarek 2001; Palmer & O'Keeffe 1990; Velinsky et al. 2006). Essentially, the water impounded behind a dam, such as that of the study site, is transformed from a free-flowing lotic system to a slow-flow or stagnant lentic system (Bednarek 2001; Haynes &Vastine 2008; Higgs 2002). Consequently, the reservoir behind the dam experiences increased temperatures, which then causes reductions in DO levels (Haas & Mark 2008; Haynes & Vastine 2008).

This was demonstrated in a 2005 study led by Victor Santucci examining the effects of multiple low-head dams on the biotic and abiotic features of a warm water river. Continuous, point, and grab sampling techniques were used to collect water quality data over twelve consecutive days from 22 sites along the river, split evenly between upstream and downstream of the dam. Results showed that water impounded behind the dam had larger daily fluctuations in DO and pH, and often did not meet state water quality standards, similar to conditions in the

Fifth Avenue Dam pool. Water below the dam tended to have less fluctuation in DO and pH, and was usually in attainment of state standards.

There are several limitations within the methodology of this study. The effect of spatial variation on water quality within the dam pool was not accounted for. Ideally, several YSI 6600 sondes would have been installed at various points in the dam pool and at various depths in the water column to capture the effect of depth and location on water quality. Gross primary productivity values are multiplied by the average river depth, which normalizes the effect of depth on productivity and produces a mean GPP for the water column at the point of sampling. Additionally, aquatic metabolism calculations were not corrected for diffusion of oxygen between the atmosphere and the river. Therefore, this study represents a simplified oxygen balance that only takes productivity and respiration into account.

Future studies should examine whether the water quality parameters investigated in this study are influenced by the removal of the Fifth Avenue Dam. Since temperatures were generally higher in the Fifth Avenue Dam pool, it could be hypothesized that temperatures will decrease post-removal. It can also be hypothesized that the removal of the Fifth Avenue Dam will stabilize DO and pH levels. Stabilizing DO can also be expected to stabilize productivity levels, contributing to better water quality in the Olentangy River.

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APPENDIX A: TABLES

Table 1: Monthly averages of parameters measured with a YSI 6600 every 30 minutes from June 2011 to January 2012, where highlighted cells indicate maximum monthly values (± standard error(N))				
Month	**Depth (m)**	**Temp (C)**	**SpCond (µS/cm)**	**DO (mg/L)**
June	0.929 ± 0.0025(1440)	22.9 ± 0.04(1440)	324 ± 2(1440)	7.61 ± 0.04(1440)
July	0.891 ± 0.0022(1488)	27.5 ± 0.03(1488)	295 ± 1(1488)	9.2 ± 0.10(1488)
August	0.868 ± 0.0011(1488)	25.3 ± 0.03(1488)	445 ± 3(1488)	9.09 ± 0.07(1488)
September	0.881 ± 0.0014(1440)	20.2 ± 0.07(1440)	345 ± 2(1440)	8.33 ± 0.04(1440)
October	1.002 ± 0.0044(1488)	12.9 ± 0.09(1488)	406 ± 4(1488)	9.88 ± 0.03(1488)
November	1.095 ± 0.0065(1440)	9.6 ± 0.03(1440)	496 ± 2 (1440)	10.23 ± 0.02(1440)
December	1.312 ± 0.0059(1488)	5.6 ± 0.03(1488)	347 ± 2(1488)	11.85 ± 0.01(1488)
January	1.114 ± 0.0060(1488)	2.5 ± 0.04(1488)	496 ± 3(1488)	13.37 ± 0.02(1488)

Table 2: Number of DO excursions below certain concentrations based on measurements taken by a YSI 6600 every 30 minutes from June 2011 to January 2012			
Month	**Below 5 mg/L (count)**	**Below 4 mg/L (count)**	**Below 3 mg/L (count)**
June	10	0	0
July	94	3	0
Aug	82	4	0
Sept	16	1	0
Oct	0	0	0
Nov	0	0	0
Dec	0	0	0
Jan	0	0	0

Table 3: Gross primary production and respiration for select dates in 2011 calculated based on the dawn-dusk-dawn method for base flow and flooding river conditions. Highlighted cells indicate maximum values.								
Date	**River Flow Conditions**	**Ave Depth (m)**	**Flow (m^3/s)**	**Dawn DO (mg/L)**	**Dusk DO (mg/L)**	**Dawn DO (mg/L)**	**GPP (g O_2/m^2- day)**	**Respiration (g O_2/m^2-day)**
June 18-19, 2011	Base flow	1.122	34.5	7.79	7.64	7.74	3.37	2.69
June 27-28, 2011	Base flow	0.8655	3.0	6.68	7.8	6.57	2.03	2.14
June 29-30, 2011	Base flow	0.8356	1.1	6.31	8.82	7.58	3.13	6.05
July 3-4, 2011	Base flow	0.8344	1.1	5.83	10.56	6.94	6.97	6.05
July 14-15, 2011	Base flow	0.8971	6.2	5.79	11.77	6.44	10.15	9.56
July 24-25, 2011	Flooding	1.2087	43.9	6.64	6.7	6.95	0.07	0.00
July 25-26, 2011	Flooding	1.158	44.2	6.95	7.42	6.44	1.68	2.28
July 26-27, 2011	Base flow	0.9678	13.8	6.34	8.18	6.09	3.80	4.04
August 11-12, 2011	Base flow	0.9611	14.3	7.11	9.09	6.93	3.98	4.15
August 19-20, 2011	Flooding	0.8486	2.3	10.18	15.11	6.41	11.57	14.77
August 20-21, 2011	Flooding	0.8509	2.0	6.41	13.58	7.83	10.99	9.78
August 26-27, 2011	Base flow	0.8554	2.6	4.11	6.02	4.03	3.34	3.41
September 11-12, 2011	Base flow	0.8823	4.4	7.13	16.04	7.82	15.11	14.51
September 20-21, 2011	Base flow	0.8589	2.3	6.5	8.78	6.3	4.09	4.26

Table 4: Data taken at foot bridge (dam pool site) and North Broadway Street Bridge (upstream reference site) with hand-held YSI 600 sonde (±standard error(n)). An un-paired T-test (α=0.05) was conducted to compare differences in data at both sites.					
Location	**Date**	**Time**	**Temp (°C)**	**DO (mg/L)**	**Conductivity (μS/cm)**
Foot Bridge	**Average**		9.22±0.44(8)	13.75±0.83(8)	428±12(8)
North Broadway			8.75 ± 0.23(12)	14.02±0.51(12)	432±10(12)
	T-Value		0.98	0.49	3.95

APPENDIX B: FIGURES

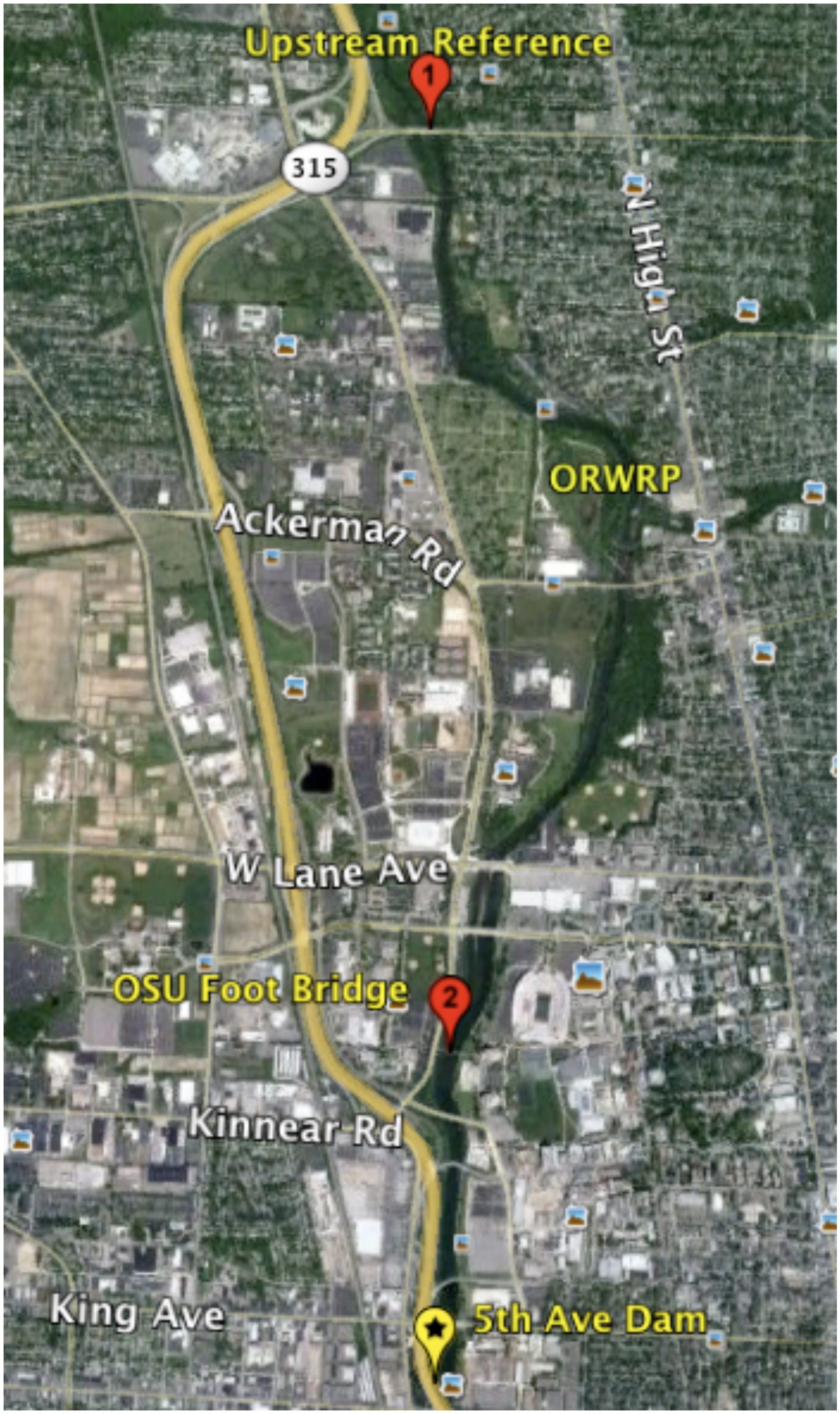
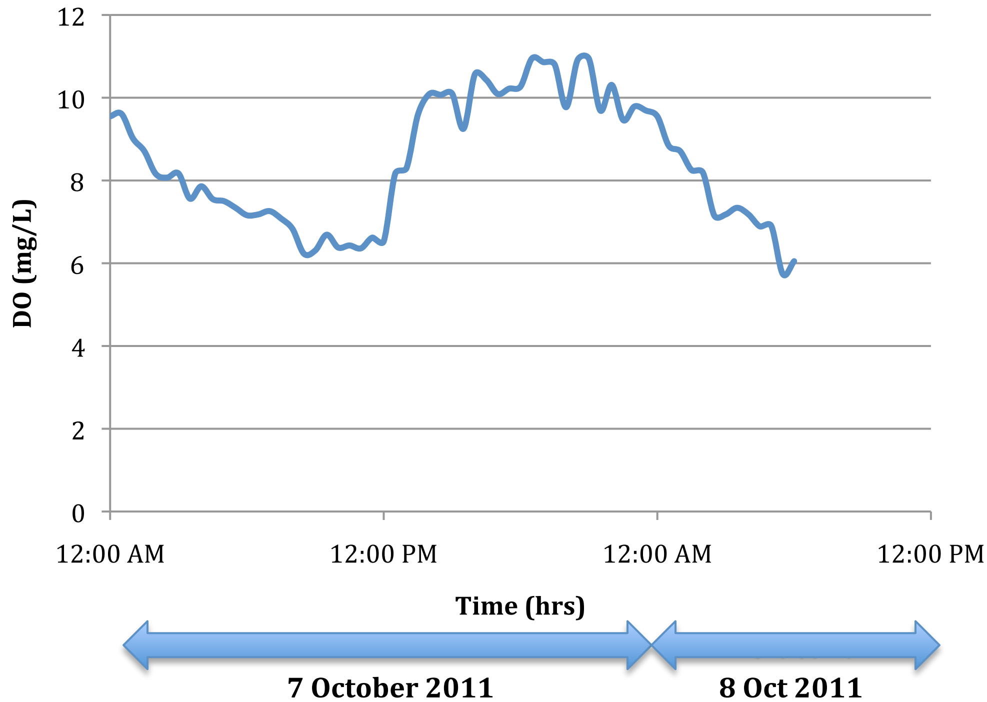


Figure 1: Data-collection sites along the impounded reach of the Olentangy River. Site 1: North Broadway St bridge; Site 2: Ohio State University foot bridge and location of YSI 6600 water sampling data sonde.

A)



B)

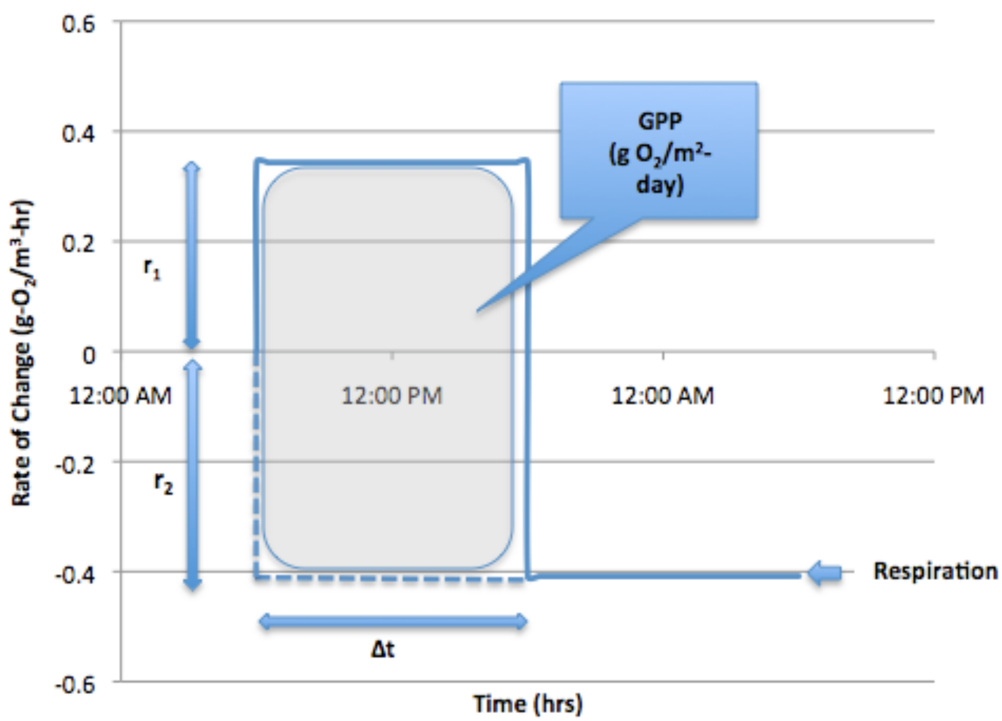


Figure 2: (A) Dissolved oxygen diurnal from midnight on October 7 to noon on October 8, 2011 based on DO readings taken by a YSI 6600 every 30 minutes. (B) Rate of change of dissolved oxygen concentration versus time for the diurnal curve from October 7-8, 2011. Shaded area represents gross primary production in g O_2/m^2-day. The dashed horizontal line represents the respiration rate in g O_2/m^3-hr.

A)

B)

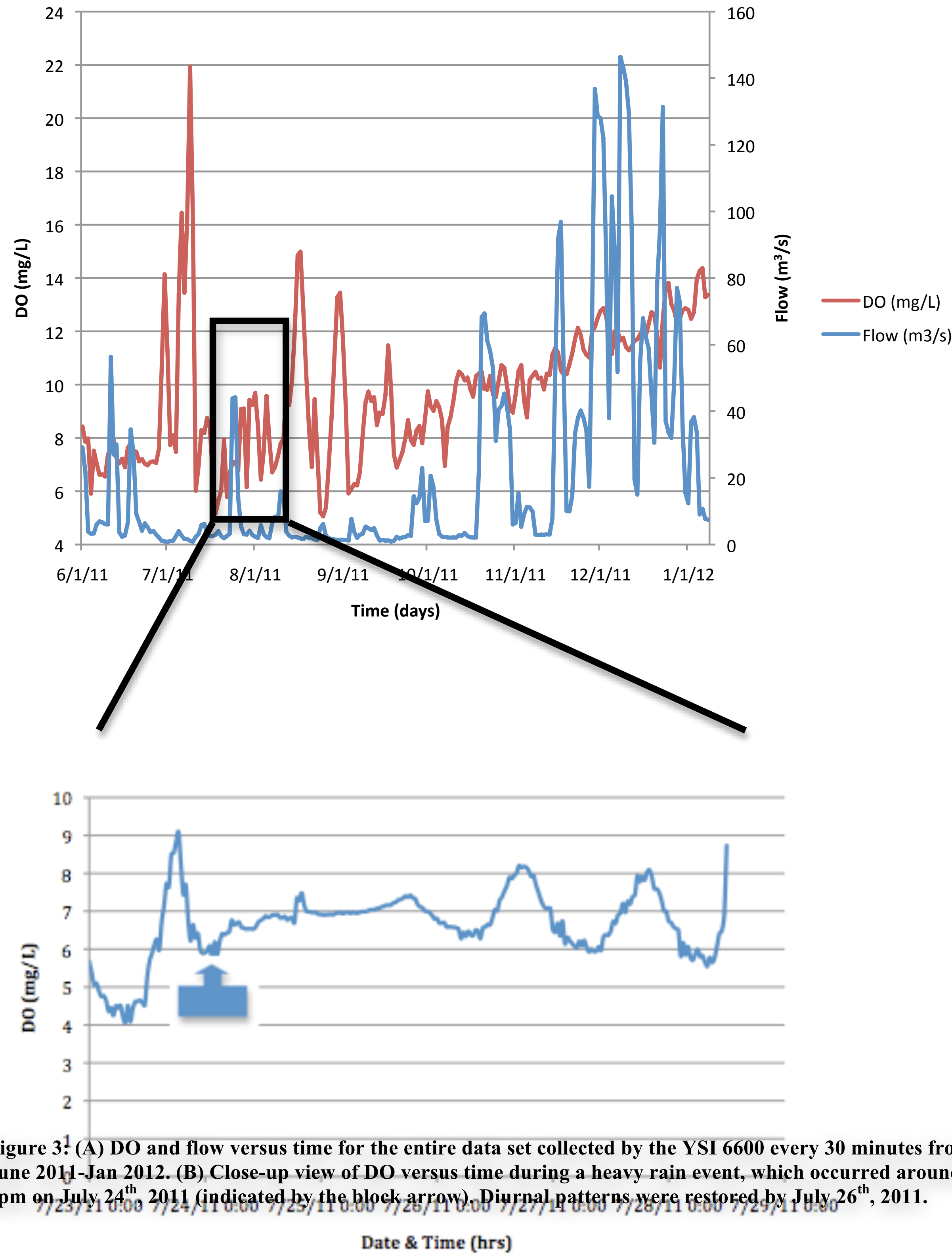


Figure 3: (A) DO and flow versus time for the entire data set collected by the YSI 6600 every 30 minutes from June 2011-Jan 2012. (B) Close-up view of DO versus time during a heavy rain event, which occurred around 5pm on July 24th, 2011 (indicated by the block arrow). Diurnal patterns were restored by July 26th, 2011.

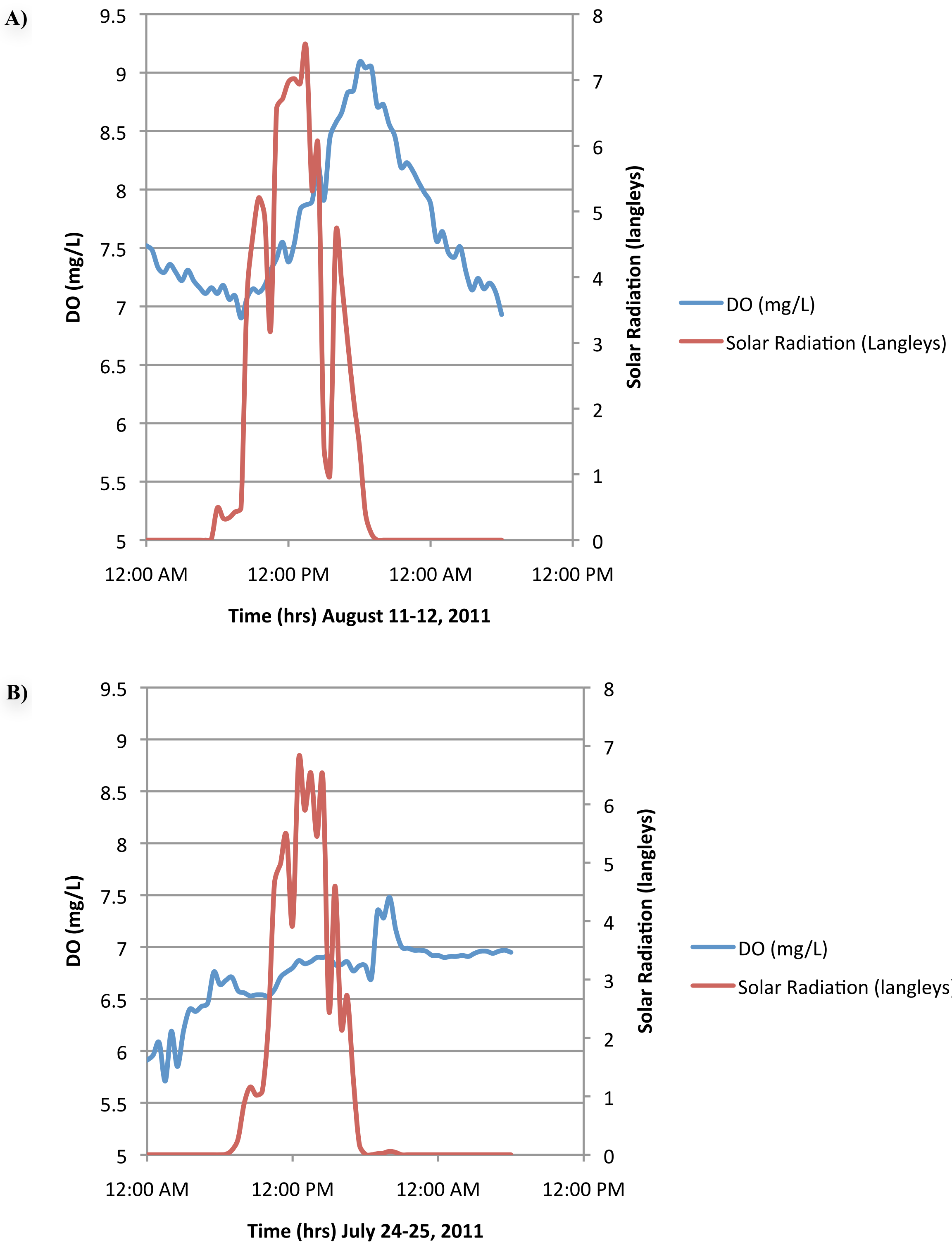


Figure 4: (A) Dissovled oxygen and solar radiation as a function of time for base flow conditions on August 11th, 2011 (14.3 m^3/s) and (B) flooding conditions on July 24, 2011 (43.9 m^3/s). DO values were recorded by a YSI 6600 every 30 minutes, and solar data were provided by the OARDC Weather System.

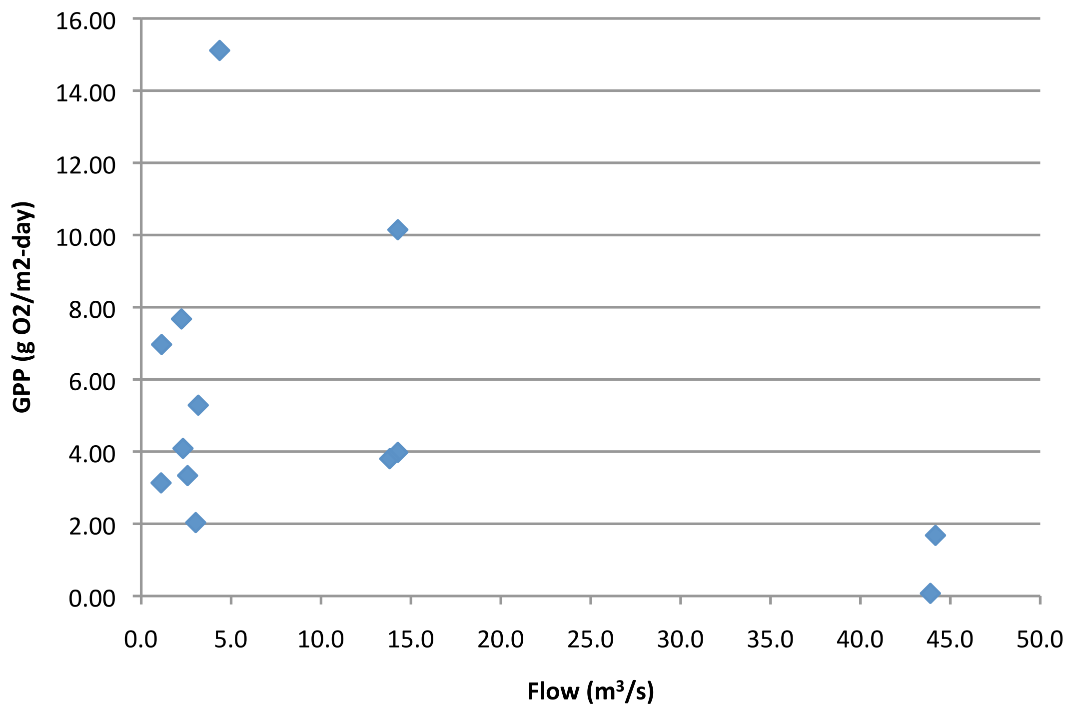


Figure 5: Gross primary productivity versus flow for various flow conditions. GPP was calculated based on the dawn-dusk-dawn method, and flow values were obtained from USGS station 03226800 near Worthington, Ohio.

APPENDIX C: RAW DATA

Table 5: Daily averages from June 2011-January 2012 of readings taken every 30 minutes by the YSI 6600 installed on the foot bridge located in the study area adjacent to Ohio State's campus. Highlighted cells indicate a period when sonde was removed for calibration.				
Date	**Depth (m)**	**Temp (C)**	**Specific Conductivity (µS/cm)**	**DO (mg/L)**
1-Jun-11	1.041	20.69	328	8.43
2-Jun-11	0.881	20.73	366	7.86
3-Jun-11	0.879	21.87	436	7.98
4-Jun-11	0.887	23.23	445	5.91
5-Jun-11	0.89	24.26	553	7.52
6-Jun-11	0.921	24.74	490	7.04
7-Jun-11	0.912	24.1	415	6.62
8-Jun-11	0.903	25.49	458	6.63
9-Jun-11	0.931	25.03	313	6.55
10-Jun-11	1.216	22.57	276	7.39
11-Jun-11	1.056	22.69	311	7.52
12-Jun-11	1.102	22.21	362	7.91
13-Jun-11	0.884	22.64	297	7.25
14-Jun-11	0.854	21.74	218	7.05
15-Jun-11	0.873	21.22	258	7.22
16-Jun-11	0.893	21.63	234	6.9
17-Jun-11	1.12	21.67	167	7.63
18-Jun-11	1.083	21.65	174	7.79
19-Jun-11	0.945	21.78	241	7.52
20-Jun-11	0.933	21.86	266	7.48
21-Jun-11	0.887	23.01	288	7.12
22-Jun-11	0.925	22.86	291	7.21
23-Jun-11	0.892	22.09	282	7.03
24-Jun-11	0.869	21.76	300	6.97
25-Jun-11	0.876	22.39	303	7.1
26-Jun-11	0.866	22.86	323	7.12
27-Jun-11	0.855	23.15	329	7.06
28-Jun-11	0.837	24.02	330	7.6
29-Jun-11	0.831	24.97	332	10.69
30-Jun-11	0.829	26.59	332	14.14
1-Jul-11	0.841	26.86	336	11.31
2-Jul-11	0.835	26.23	338	7.73
3-Jul-11	0.839	26.8	349	8.09
4-Jul-11	0.877	26.61	367	7.48
5-Jul-11	0.864	26.68	336	13.39
6-Jul-11	0.856	27.24	288	16.45
7-Jul-11	0.871	26.58	274	13.45
8-Jul-11	0.837	26.66	270	16.33
9-Jul-11	0.828	27.9	250	21.93

10-Jul-11	0.907	27.37	248	16.15
11-Jul-11	0.878	25.48	252	6.02
12-Jul-11	0.883	26.71	313	6.95
13-Jul-11	0.897	26.26	317	8.29
14-Jul-11	0.875	25.95	294	8.18
15-Jul-11	0.856	26.11	293	8.75
16-Jul-11	0.853	26.76	301	8.36
17-Jul-11	0.862	27.26	318	6.64
18-Jul-11	0.889	27.86	317	5.16
19-Jul-11	0.864	28.99	307	5.65
20-Jul-11	0.849	29.27	322	6.03
21-Jul-11	0.856	30.91	303	7.94
22-Jul-11	0.879	30.07	278	5.79
23-Jul-11	1.194	26.69	226	6.68
24-Jul-11	1.191	27.04	248	7.07
25-Jul-11	0.982	28.1	275	7.09
26-Jul-11	0.895	27.66	270	6.79
27-Jul-11	0.87	28.81	284	9.09
28-Jul-11	0.88	29.03	289	9.1
29-Jul-11	0.884	28.07	269	6.15
30-Jul-11	0.861	28.37	308	9.43
31-Jul-11	0.856	28.11	291	9.24
1-Aug-11	0.85	27.87	299	9.69
2-Aug-11	0.911	26.99	281	8.4
3-Aug-11	0.873	26.07	266	6.44
4-Aug-11	0.852	26.51	288	7.48
5-Aug-11	0.847	27.55	292	9.58
6-Aug-11	0.885	27.43	309	7.94
7-Aug-11	0.942	26.16	385	6.71
8-Aug-11	0.929	25.8	362	6.9
9-Aug-11	0.974	25.63	418	7.3
10-Aug-11	0.974	25.09	425	7.79
11-Aug-11	0.881	24.64	429	7.97
12-Aug-11	0.856	25.23	445	9.8
13-Aug-11	0.847	24.82	476	9.23
14-Aug-11	0.849	24.29	510	10.13
15-Aug-11	0.848	24.1	528	12.06
16-Aug-11	0.846	25.09	537	14.85
17-Aug-11	0.842	25.8	538	14.99
18-Aug-11	0.842	26.08	550	12.8
19-Aug-11	0.854	26.12	572	10.46
20-Aug-11	0.841	25.95	580	8.38
21-Aug-11	0.841	24.93	554	6.91
22-Aug-11	0.836	25.04	468	9.45
23-Aug-11	0.888	24.2	344	7.31
24-Aug-11	0.914	24.8	411	5.2
25-Aug-11	0.858	24.74	414	5.06

26-Aug-11	0.841	24.68	432	5.39
27-Aug-11	0.835	24.44	486	7.02
28-Aug-11	0.834	23.88	524	8.79
29-Aug-11	0.835	23.31	545	11.05
30-Aug-11	0.835	23.59	565	13.27
31-Aug-11	0.835	24.61	576	13.45
1-Sep-11	0.834	25.55	581	11.7
2-Sep-11	0.833	27.42	576	9.17
3-Sep-11	0.939	25.55	518	5.92
4-Sep-11	0.88	22.69	438	6.09
5-Sep-11	0.846	20.64	454	6.27
6-Sep-11	0.859	19.91	350	6.22
7-Sep-11	0.876	19.47	285	6.72
8-Sep-11	0.888	19.79	304	8.16
9-Sep-11	0.885	21.09	309	9.34
10-Sep-11	0.88	21.93	303	9.74
11-Sep-11	0.888	22.29	295	9.39
12-Sep-11	0.867	22.24	286	9.53
13-Sep-11	0.836	22.08	290	8.48
14-Sep-11	0.852	20.82	296	8.95
15-Sep-11	0.837	18.91	294	8.9
16-Sep-11	0.837	18.21	293	9.59
17-Sep-11	0.833	18.79	306	11.47
18-Sep-11	0.845	19	327	9.82
19-Sep-11	0.861	19.32	345	7.38
20-Sep-11	0.85	19.91	358	6.89
21-Sep-11	0.851	20.61	359	7.17
22-Sep-11	0.858	19.82	357	7.46
23-Sep-11	0.871	18.45	345	7.97
24-Sep-11	0.856	18.26	339	8.67
25-Sep-11	0.98	18.63	321	7.92
26-Sep-11	0.969	18.08	289	7.74
27-Sep-11	0.945	17.53	289	8.29
28-Sep-11	1.054	17.76	289	8.44
29-Sep-11	0.932	17.18	269	7.8
30-Sep-11	0.899	14.46	276	8.72
1-Oct-11	0.995	13.21	283	9.75
2-Oct-11	1.001	14.49	281	9.18
3-Oct-11	0.92	14.93	283	9.02
4-Oct-11	0.877	15.9	282	9.38
5-Oct-11	0.856	16.61	251	9.16
6-Oct-11	0.851	17.46	261	8.68
7-Oct-11	0.851	17.62	273	6.95
8-Oct-11	0.851			
9-Oct-11	0.851			
10-Oct-11	0.85			
11-Oct-11	0.882			

12-Oct-11	0.865			
13-Oct-11	0.871			
14-Oct-11	0.859			
15-Oct-11	0.85			
16-Oct-11	0.851			
17-Oct-11	0.853	14.1	670	8.42
18-Oct-11	1.025	13.58	557	8.78
19-Oct-11	1.337	12.28	351	9.37
20-Oct-11	1.334	12.33	478	10.13
21-Oct-11	1.278	12.23	505	10.49
22-Oct-11	1.258	11.87	480	10.39
23-Oct-11	1.248	11.78	428	10.16
24-Oct-11	1.093	11.32	428	10.27
25-Oct-11	1.147	12.33	407	9.84
26-Oct-11	1.143	12.32	399	9.55
27-Oct-11	1.187	10.47	407	10.32
28-Oct-11	1.154	10.11	422	10.42
29-Oct-11	1.132	9.93	450	10.48
30-Oct-11	0.915	10.14	489	9.84
31-Oct-11	0.887	9.73	554	9.81
1-Nov-11	0.981	9.76	541	10.33
2-Nov-11	0.884	10.25	504	9.63
3-Nov-11	0.914	11.03	563	9.53
4-Nov-11	0.942	9.95	530	10.14
5-Nov-11	0.943	8.93	512	10.73
6-Nov-11	0.938	9.5	514	10.63
7-Nov-11	0.876	10.85	519	9.93
8-Nov-11	0.864	11.43	546	9.11
9-Nov-11	0.869	10.73	601	8.95
10-Nov-11	0.862	9.12	650	9.63
11-Nov-11	0.867	8.08	662	10.5
12-Nov-11	0.871	8.46	660	10.73
13-Nov-11	0.915	11.25	581	9.41
14-Nov-11	1.17	12.86	417	8.77
15-Nov-11	1.419	10.69	497	10.18
16-Nov-11	1.494	10.09	519	10.34
17-Nov-11	1.277	8.94	442	10.48
18-Nov-11	0.954	8.14	443	10.23
19-Nov-11	0.945	9.23	491	10.26
20-Nov-11	0.968	10.33	472	9.82
21-Nov-11	1.117	9.46	426	10.41
22-Nov-11	1.16	9.61	388	10.36
23-Nov-11	1.162	8.18	417	11.13
24-Nov-11	1.142	7.95	460	11.38
25-Nov-11	1.129	8.34	488	11.2
26-Nov-11	1.022	9.57	498	10.52
27-Nov-11	1.26	9.95	441	10.37

28-Nov-11	1.67	9.48	402	10.39
29-Nov-11	1.635	8.43	376	10.76
30-Nov-11	1.589	7.57	329	11.17
1-Dec-11	1.622	6.65	299	11.72
2-Dec-11	1.413	5.86	312	12.13
3-Dec-11	1.184	5.85	344	11.86
4-Dec-11	1.431	7.49	344	11.31
5-Dec-11	1.597	7.32	249	11.12
6-Dec-11	1.123	6.36	346	11.02
7-Dec-11	1.691	5.73	312	11.98
8-Dec-11	1.675	5.61	253	12.16
9-Dec-11	1.656	4.75	226	12.5
10-Dec-11	1.612	3.89	236	12.77
11-Dec-11	1.505	3.35	275	12.87
12-Dec-11	1.035	3.34	366	12.56
13-Dec-11	0.993	4.7	421	11.75
14-Dec-11	1.208	7.11	396	11.15
15-Dec-11	1.316	5.41	395	12
16-Dec-11	1.276	5.26	420	12.01
17-Dec-11	1.256	5.78	364	11.66
18-Dec-11	1.202	5.32	350	11.76
19-Dec-11	1.093	5.96	401	11.41
20-Dec-11	1.343	7.03	352	11.29
21-Dec-11	1.414	6.76	378	11.43
22-Dec-11	1.694	7	330	11.65
23-Dec-11	1.15	6.32	343	11.7
24-Dec-11	1.112	5.69	348	11.89
25-Dec-11	1.098	5.99	344	11.87
26-Dec-11	1.159	5.77	342	11.82
27-Dec-11	1.355	4.9	316	12.28
28-Dec-11	1.349	4.22	345	12.72
29-Dec-11	1.158	4.3	422	12.63
30-Dec-11	0.994	5.6	468	11.81
31-Dec-11	0.965	5.58	475	10.64
1-Jan-12	1.097	3.88	445	12.47
2-Jan-12	1.132	2.15	417	13.55
3-Jan-12	1.125	1.58	432	13.82
4-Jan-12	0.95	2.37	452	13.03
5-Jan-12	0.955	3.11	497	12.78
6-Jan-12	0.928	3.99	501	12.31
7-Jan-12	0.92	3.73	520	12.48
8-Jan-12	0.924	3.18	523	12.79
9-Jan-12	0.925	3.02	522	12.87
10-Jan-12	0.936	2.96	545	12.81
11-Jan-12	0.954	3.81	595	12.47
12-Jan-12	0.965	2.6	605	12.72
13-Jan-12	0.965	0.52	572	13.96

14-Jan-12	0.94	0.27	590	14.26
15-Jan-12	0.944	0.2	595	14.37
16-Jan-12	1.051	2.68	633	13.28
17-Jan-12	1.203	2.9	542	13.38
18-Jan-12	1.266	1.04	553	14.26
19-Jan-12	0.983	0.58	543	14.06
20-Jan-12	0.965	0.08	604	14.26
21-Jan-12	0.962	0.33	632	14.1
22-Jan-12	1.139	2.97	736	13.16
23-Jan-12	1.337	2.71	433	13.64
24-Jan-12	1.278	1.81	459	14.24
25-Jan-12	1.386	2.91	417	13.57
26-Jan-12	1.587	4.08	346	12.82
27-Jan-12	1.041	3.85	436	12.65
28-Jan-12	1.495	2.74	379	13.62
29-Jan-12	1.562	2.76	301	13.75
30-Jan-12	1.657	3.3	267	13.58
31-Jan-12	1.518	3.95	278	13.34

Table 6: Data taken at foot bridge and North Broadway Street Bridge (upstream reference site) with hand-held YSI 600 sonde.

Location	Date	Time	Temp (°C)	DO (mg/L)	Cond (μS/cm)
Foot Bridge East	29-Oct-11	3:37pm	8.31	12.34	398
	31-Oct-11	3:15pm	9.38	17.34	436
	5-Nov-11	3:50pm	7.92	14.3	402
	7-Nov-11	4:10pm	11.03	11.55	459
Foot Bridge West	29-Oct-11	3:39pm	8.29	10.34	385
	31-Oct-11	3:16pm	9.25	16.28	468
	5-Nov-11	3:48pm	8.41	14.28	411
	7-Nov-11	4:09pm	11.06	13.58	461
North Broadway East	29-Oct-11	3:50pm	8.62	13.74	390
	31-Oct-11	3:30pm	8.59	17.94	468
	5-Nov-11	2:57pm	8.67	13.03	420
	7-Nov-11	3:11pm	10.61	15.42	470
North Broadway Central	29-Oct-11	3:51pm	8.46	13.42	394
	31-Oct-11	3:31pm	8.28	15.78	465
	5-Nov-11	3:00pm	7.97	11.67	408
	7-Nov-11	3:14pm	9.51	12.83	454
North Broadway West	29-Oct-11	3:52pm	8.51	14.07	389
	31-Oct-11	3:32pm	8.55	14.88	469
	5-Nov-11	3:03pm	7.67	11.97	401
	7-Nov-11	3:16pm	9.59	13.52	454